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Short Communication

Effect of silica-modified ceramic separator for electricity generation in cellulose-fed microbial fuel cell

Pimprapa Chaijak[1,2,*], Santipap Sotha[3] and Watcharasorn Kaoplod[3]

[1]Microbial Fuel Cell & Bioremediation Laboratory, Faculty of Science, Thaksin University;
[2]Microbial Technology for Agriculture, Food and Environment Research Center, Thaksin University;
[3]Department of Biology, Faculty of Science, Thaksin University, Thailand.

ABSTRACT

A microbial fuel cell is a well-known biological device that can convert chemical energy to electrical energy without the combustion process. This technology still provides a limit of operation owing to its structural cost like proton exchange membrane. In this study, the silica-modified ceramic separator was developed for use in the cellulose-fed MFC. The maximal current density and power density of 27.00 ± 0.10 A/m^3 and 1.46 ± 0.05 W/m^3 were obtained. This study would help in gaining new knowledge about using the silica-modified ceramic separator integrated with cellulose-fed MFC for electricity generation.

KEYWORDS: ceramic separator, microbial fuel cell, electricity generation, proton exchange membrane.

1. INTRODUCTION

A microbial fuel cell (MFC) is one of the most important devices that can convert chemical energy from organic and inorganic materials to electrical energy. MFC can also be used as a biological treatment system for various wastewaters for chemical oxygen demand (COD) removal and simultaneously generating electricity [1]. Previous studies have shown that MFC has a high potential for recovering electrical energy from various substrates such as rubber wastewater [2], palm oil mill wastewater [3], aquacultural wastewater [4], brewery wastewater [5], pharmaceutical wastewater [6], human feces [7], and lignocellulolytic waste [8].

Cellulose ($(C_6H_{10}O_5)_n$) is the fibrous biopolymer that is obtained from a cell wall component of plants, bacteria and algae. It is of interest as it is used as a substrate for electrochemical devices, especially MFC owing to its vast availability in the environment [9]. For energy production, cellulose must degrade into the form of a monosaccharide such as glucose. Thus, the cellulose-degrading consortium has been developed to gain the energy stored in the cellulose molecule [10]. The cellulose-fed MFC has been studied to obtain alternative energy from the lignocellulosic substrate without a combustion process. In Rezaei *et al.*, the maximal power output of 0.012 W/m^2 was gained from the two-chamber MFC [11]. Moreover, the maximal power density of 0.066 W/m^2 was generated from the dual-chamber MFC where the planktonic bacterial communities were used as an anode biocatalyst and operated for 10 weeks [12].

The ceramic separator has gained interest in MFC large-scale studies as it can reduce 60% of the MFC component cost. Various operation models of ceramic separator MFC (CMFC) have been developed for operation under realistic conditions. Moreover, some results have indicated that the ceramic separator can provide long-term stability for up to 19 months [13]. The goethite-modified

*Corresponding author: chaijak.pimprapa@gmail.com

ceramic separator has been used by Das *et al*. for proton exchange membrane. The result indicated that the maximal power density of 0.112 W/m^2 was produced [14]. To enhance the hydration of the ceramic separator, a hygroscopic oxide such as silica (SiO_2) has been used, which forms a silicon-oxygen tetrahedron and provides the negatively charged center for helping the cation exchange [15].

This study aims to synthesize the silica-blended natural clay ceramic separator to be used as a proton exchange membrane in MFC and evaluate its properties like water uptake, cation transport number and its applicability in MFC.

2. MATERIALS AND METHODS

2.1. Chemicals and materials

All chemicals used were of analytical grade and purchased from Sigma-Aldrich, United States. Deionized water was used for synthetic wastewater preparation. The nutrient broth (NB) was purchased from Himedia, India. Silica powder and ceramic soil were procured from the local store in Southern Thailand. The Nafion 117 membrane was purchased from Fuel Cell Store, United State. The graphite plate electrode was obtained from a local store in Central Thailand.

2.2. Ceramic separator preparation

The modified ceramic separator was prepared according to a modified method by Raychaudhuri *et al*. [15]. Briefly, 30% (w/w) of silica powder (SiO_2) was mixed with 70% (w/w) natural clay. The 2 mm thickness silica-modified ceramic plate was prepared and dried at 80 ºC in a hot air oven for 7 days. The dried modified ceramic plate was baked in a muffle furnace at 680 ºC for 30 mins.

2.3. Water uptake

The water uptake property of the membrane was studied based on the weight of the ceramic membrane before and after dehydration for 24 hr at 120 ºC according to the study by Li *et al*. [16]. 100% (w/w) natural clay ceramic plate was used as the negative control. The Nafion 117 membrane was used as the positive control. The water uptake was calculated by Eq. (1):

$$\text{Water uptake (\%)} = [(W_{before} - W_{after}) / W_{after}] \times 100 \quad (1)$$

where W_{before} is the weight before dehydration (wet weight) and W_{after} is the weight after dehydration (dry weight).

2.4. Cation transport number

The cation transport number was calculated according to Das *et al*. [14], and Neethu *et al*. [17]. The $Ag/AgCl_2$ reference electrodes were immersed in the anode and cathode chamber. 0.05 M KCl was used as the anolyte and 0.01 M KCl was used as the catholyte. The voltage of the cell was measured after cell set-up for 3 mins. The cation transport number was calculated according to the study of Das *et al.* [14].

2.5. MFC construction

The dual-chamber MFC used in this experiment is shown in Figure 1. 40 mL cell culture flasks were used as an MFC chamber. The electrodes were made from the 20 cm^2 microwave-treated graphite plate. 1.0% (w/v) of carboxymethyl cellulose (CMC) solution (modified from Kaoplod and Chaijak [18]) was used as the anolyte. 1M $KMnO_4$ solution was used as the catholyte.

2.6. MFC operation

10% (v/v) of cellulose-degrading bacteria *Bacillu*s sp. WK21 (1.0×10^8 cell/mL) was mixed with the sterile CMC solution and added to an anode chamber. The culture was incubated for 48 hr for immobilizing the bacteria on the surface of the anode electrode. The anolyte was fed out, then the fresh sterile CMC solution was fed in and the opened-circuit voltage (OCV) was collected every 10 mins. The closed-circuit voltage (CCV) was determined at 1-5,000 Ω of external resistance. The electrochemical properties were calculated according to Ohm's law and the polarization curve was plotted.

3. RESULTS AND DISCUSSION

The silica-modified ceramic separator was made from 30% (w/w) silica and 70% (w/w) natural clay using a pyrolysis process (30 min) at the temperature of 680 ºC. Whereas 100% (w/w) natural clay was used as the negative control, the positive control was made from the Nafion 117

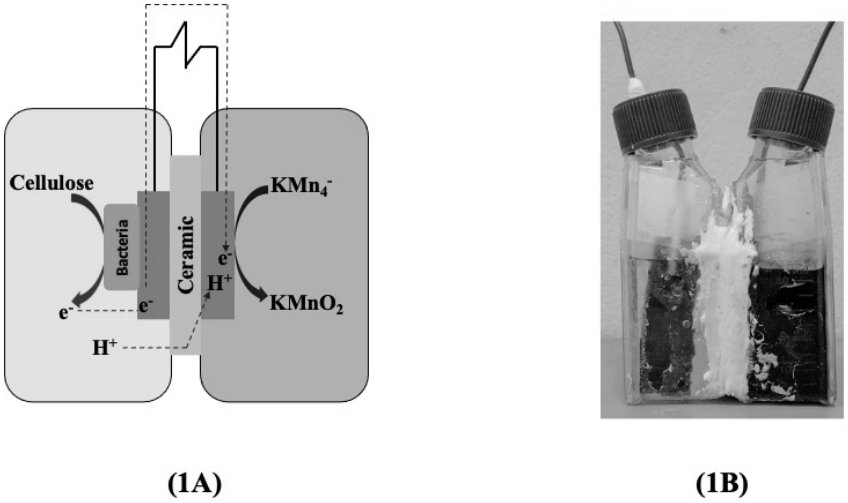

Figure 1. Diagram of the dual-chamber MFC with silica-modified ceramic (1A); and photograph of the dual-chamber MFC (1B).

membrane. Water uptake of modified ceramic, negative control and positive control was found to be 19.50 ± 0.50%, 31.70 ± 0.10% and 15.50 ± 0.50% respectively. The cation transport number serves as an indicator of the positive ion transport potential of a separator. The modified ceramic separator showed a 37.50% higher cation transport number than the negative control.

For MFC set-up, the cellulose-degrading bacterium *Bacillus* sp. WK21 [18] was immobilized on the surface of the anodic electrode. The 48 hr-old active culture was used for electricity generation. A 2-mm thick modified ceramic separator was used as the proton exchange membrane. The OCV was monitored, and the maximal OCV of 0.724 ± 0.003 V was gained from the dual-chamber MFC with a modified ceramic separator. The maximal OCV of 0.653 ± 0.029 V and 0.529 ± 0.009 V was generated from the positive control (Nafion 117) and negative control (natural clay ceramic), respectively (Figure 2).

The maximal current density (CD) of dual-chamber MFC with the modified ceramic separator was 27.00 ± 0.10 A/m^3 and the maximal power density (PD) was 1.46 ± 0.05 W/m^3 (Figure 3). However, the current density and power density produced based on the electrode area were 0.54 ± 0.01 A/m^2 and 0.07 ± 0.00 W/m^2 respectively.

The maximal current density and power density of 15.00 ± 0.10 A/m^3 and 2.25 ± 0.05 W/m^3 were generated from the positive control (Figure 4). Figure 5 shows that the maximal current density and power density of 7.50 ± 0.00 A/m^3 and 0.13 ± 0.01 W/m^3 were gained from the negative control.

On the other hand, the ceramic separator synthesized from the natural clay generated the maximal OCV of 529.0 ± 2.4 mV wherein fresh human urine was used as the anolyte. The maximal power output of 6.58 W/m^3 was produced [19]. Khalili *et al*. [20] showed that the maximal power density of a 9-mm thick natural clay ceramic separator integrated with MFC was 0.32 W/m^2 wherein domestic wastewater was used as the substrate. Moreover, the silica oxide-modified ceramic separator generated a maximal power output of 0.77 A/m^2 when it was applied to the MFC [21]. No previous study has reported the use of a ceramic-separator MFC for electricity generation from the cellulose-based substrate.

For cellulose-fed MFC, the maximal power output of 0.05 W/m^2 was generated from the dual-chamber cellulose-fed microbial fuel cell wherein Ultrex proton-exchange membrane was used as the separator [22]. Ishii *et al*. [13] indicated that the dual-chamber MFC with a cation-membrane separator produced an electrical power of 0.01 W/m^2. Moreover, the corn straw hydrolyze-fed MFC with the active consortium can generate the maximal power density of 0.02 W/m^2 [23].

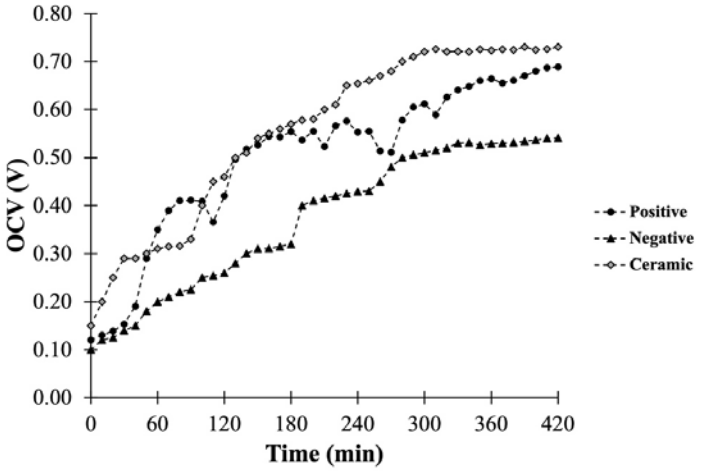

Figure 2. The opened-circuit voltage (OCV) of the dual-chamber MFC with modified ceramic.

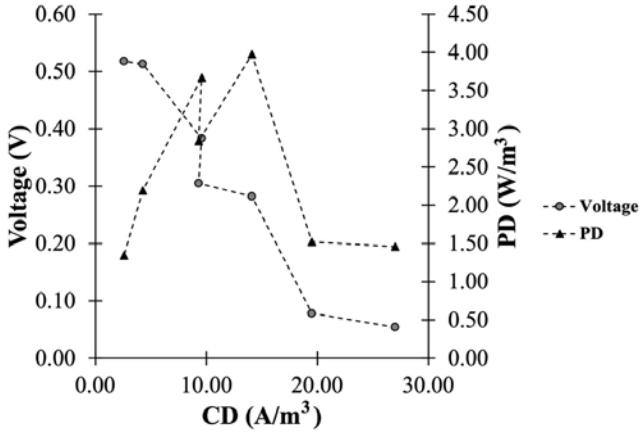

Figure 3. The polarization curve of the dual-chamber MFC with silica-modified ceramic separator.

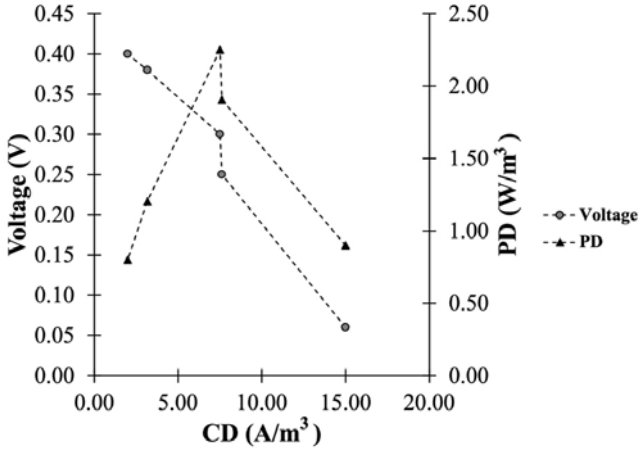

Figure 4. The polarization curve of the dual-chamber MFC with Nafion 117 (positive control).

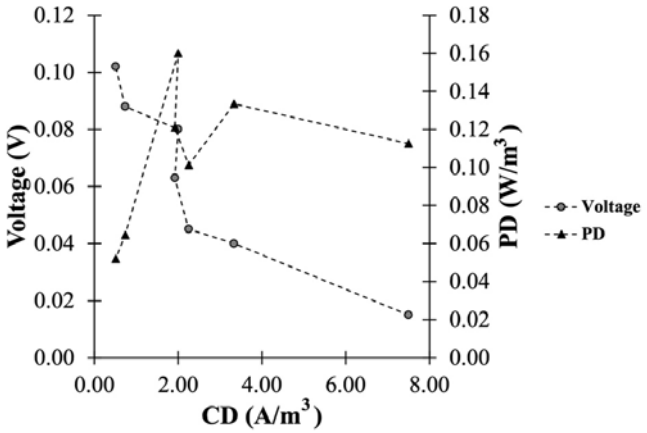

Figure 5. The polarization curve of the dual-chamber MFC with natural clay separator (negative control).

4. CONCLUSION

In this work, the 30% (w/w) silica-modified ceramic separator showed a promising potential for electricity generation in the dual-chamber MFC than the commercial proton exchange membrane (Nafion 117) and natural ceramic clay separator. These results provide new knowledge on the use of silica-modified ceramic separator coupled with cellulose-fed dual-chamber MFC for electricity generation.

AUTHOR CONTRIBUTIONS

Conceptualization and methodology, PC; investigation, SS and WK; writing, editing and data curation, PC.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

REFERENCES

1. Munoz-Cupa, C., Hu, Y., Xu, C. and Bassi, A. 2021, Sci. Total Environ., 754, 142429.
2. Chaijak, P., Sukkasem, C., Lertworapreecha, M., Boonsaweng, P., Wijasika, S. and Sato, C. 2018, J. Microbiol. Biotechnol., 28, 1360.
3. Chaijak, P., Lertworaoreecha, M. and Sukkasem, C. 2018, Pol. J. Environ. Stud., 27, 39.
4. Chaijak, P., Sato, C., Paucar, N., Sukkasem, C. and Lertworapreecha, M. 2019, Sydowia, 71, 11.
5. Negassa, L. W., Mohiuddin, M. and Tiruye, G. A. 2021, J. Water Proc. Engineer., 41, 102018.
6. Jiang, J., Wang, H., Zhang, S., Li, S., Zeng, W. and Li, F. 2021, Bioresour. Technol., 336, 125308.
7. Du, F., Li, Z., Yang, S., Xie, B. and Liu, H. 2011, Acta Astronaut., 68, 1537.
8. Sani, A., Savla, N., Pandit, S., Mathuriya, A. S., Gupta, P. K., Khanna, N., Babu, R. P. and Kumar, S. 2021, Sust. Ener. Technol. Assess., 48, 101572.
9. Wang, Z., Lee, Y. H., Kim, S. W., Seo, J. Y., Lee, S. Y. and Nyholm, L. 2021, Adv. Mater., 33, 2000892.
10. Tsavkelova, E. A. and Netrusov, A. I. 2012, Appl. Biochem. Microbiol., 48, 421.
11. Rezaei, F., Richard, T. L., Logan, B. E. 2008, Biotechnol. Bioeng., 8, 6.
12. Rismani-Yazdi, H., Christy, A. D., Carver, S. M., Yu, Z., Dehority, B. A. and Tuovinen, O. H. 2011, Bioresour. Technol., 102, 278.
13. Gajda, I., Obata, O., Salar-Garcia, M. J., Greenman, J. and Ieropoulos, I. A. 2020, Bioelectrochem., 133, 107459.
14. Das, I., Das, S., Dixit, R. and Ghangrekar, M. M. 2020, Ionics, 26, 3061.

15. Raychaudhuri, A., Sahoo, R. N. and Behera, M. 2021, Water Sci. Technol., 84, 66.
16. Li, C., Wang, L., Wang, X., Kong, M., Zhang, Q. and Li, G. 2017, J. Menbran. Sci., 527, 35.
17. Neethu, B., Bhowmick, G. D. and Ghangrekar, M. M. 2018, Biochem. Eng. J., 133, 205.
18. Kaoplod, W. and Chaijak, P. 2022, Microbiol. Biotechnol. Lett., 50, 1.
19. Pasternak, G., Greenman, J. and Ieropoulos, I. 2016, ChemSusChem, 9, 88.
20. Khalili, H. B., Mohebbi-Kalhori, D. and Afarani, M. S. 2017, Int. J. Hydrogen Ener., 42, 8233.
21. Cheraghipoor, M., Mohebbi-Kalhori, D., Noroozifar, M. and Maghsoodlou, M. 2021, Fuel, 284, 118938.
22. Ishii, S., Shimoyama, T. and Watanabe, K. 2008, BMC Microbiol., 8, 1.
23. Li, F., An, X., Wu, D., Xu, J., Chen, Y., Li, W., Cao, Y., Guo, X., Lin, X., Li, C., Liu, S. and Song, H. 2019, Front. Microbiol., 10, 409.